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SURFICIAL GEOLOGY OF BEAR LAKE VALLEY, UTAH

by

Allen D. Willard

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1959

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Allen D. Willard

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INTRODUCTION

Location

Bear Lake Valley is located in southeastern Idaho and northeastern Utah. It is an elongate valley extending from the vicinity of Laketown, Utah, in the Randolph quadrangle, to the vicinity of Georgetown, Idaho, in the Montpelier quadrangle. The southern part of the valley is occupied by Bear Lake. The essentially straight-sided valley is bounded on the northeast by the Preuss Range, on the southeast by the Bear Lake Plateau, and on the west by the Bear River Range.

Bear River, rising in the Uinta Mountains to the south, and skirting the Wyoming Basin as it swings from Wyoming into Utah and back into Wyoming again, enters the valley between the Bear Lake Plateau and the Preuss Range and then flows northward along the valley to its northern end. The river flows northward from Bear Lake Valley to near Soda Springs, Idaho, where it turns southward, flowing through Gentile and Cache Valleys, and empties into the Great Salt Lake.

Although well within the Middle Rocky Mountain province as defined by Fenneman (1917), Bear Lake Valley appears in part at least to be bounded by high-angle faults of the Basin and Range type, and thus represents an eastward extension of "Basin and Range" structure into the Middle Rocky Mountain province. It is probably similiar in basic structure to the "back valleys" of the Wasatch Mountains such as Heber, Morgan, Ogden, and Mantua Valleys (Gilbert, 1928, p. 55-62).

This study is concerned with that portion of Bear Lake Valley which lies in Utah. The Utah portion is about one-third of the whole valley

and encompasses an area of about 180 square miles.

Statement of Problem

To date almost all geologic mapping done in the United States has been directed primarily to bedrock geology. Surficial deposits have been greatly generalized and areas covered deeply with mantle have been largely neglected. Only recently have the alluviated basins received attention. Now surficial maps occasionally appear paired with bedrock maps of the same area, and the geology of the deeply alluviated basins of the west has begun to receive much needed attention as exemplified by the post-war studies of the Lahontan and Bonneville basins by the U. S. Geological Survey (Hunt et al., 1953).

Bear Lake Valley is one of the important basins of northern Utah. An important agriculture area, one of the largest in Rich County, occupies the alluviated area at the south end of Bear Lake. A small but important ground water reservoir is present in the alluvium. Bear Lake itself is one of Utah's most important recreational assets, valuable for fishing, boating, and swimming. At the same time it provides reservoir space for the regulation of Bear River, one of the most highly developed systems of hydro-electric power in the United States. For all those reasons a greater knowledge of the geology of Bear Lake Valley is necessary.

The abandoned shore lines of Bear Lake are evidence of its earlier expansion, probably in Pleistocene time when Lake Bonneville existed. The study of these abandoned shore features promises to provide additional information of the late Pleistocene history of northern Utah.

Previous Work

The early geologic work conducted in this area was by the Hayden Survey (1872, p. 100-156) and the Fortieth Parallel Survey (1877-78, p. 326-339, 393-442). Detailed geologic work by the U. S. Geological Survey followed the discovery of phosphate rock in southeastern Idaho and Rich County, Utah. A complete coverage of southeastern Idaho was reported by Mansfield (1927). Richardson (1941) reported on the geology and the mineral resources of the Randolph quadrangle in northeastern Utah. A collection and summation of recent investigations in this area is presented in the Intermountain Association of Petroleum Geologists Guidebook (1953). This includes the work of various oil companies, governmental agencies, and universities.

Pleistocene lake history has been extensively studied in numerous areas. The relatively near-by Lake Bonneville has had considerable attention in the past. G. K. Gilbert's (1890) lengthy report is the definitive statement of the features and history of the lake. More recent analysis of Lake Bonneville's history has enumerated many details, notably the paper by Hunt, Varnes, and Thomas (1953). A recent investigation by Broecker and Orr (1958) on the radiocarbon dating of the Bonneville sediments presents an interesting application of time relationships to the sediments of this lake.

Field Procedure

The field work for this investigation was carried out during the summer of 1958. Identification and location of the former shore lines of Bear Lake necessitated the making of numerous profiles in Bear Lake Valley. Various reference levels were used for these profiles. When a

profile was made in the vicinity of the lake, the water level was used as a reference or datum for the profile. The elevation of the lake for any particular day was obtained from Lifton Pumping Station where automatic level recorders are always in operation. Other reference points included the U. S. Geological Survey bench marks, Utah and Idaho Department of Highway bench marks, and elevations along the Union Pacific railroad at the mileposts. Since the topographic expression for each of the former levels of the lake was not everywhere evident, level lines were used for delineating the areas covered by the different stages. The plane table and alidade were used for most of these surveys, but where short distances were involved the hand level was used.

The geologic map of the Randolph quadrangle prepared by Richardson (1941) served as a guide to the bedrock geology of the area. Features of surficial geology were mapped on acetate overlays on aerial photographs of the area. Fathograms and a preliminary map of the sediments of Bear Lake, made available by J. Stewart Williams, were studied for this investigation.

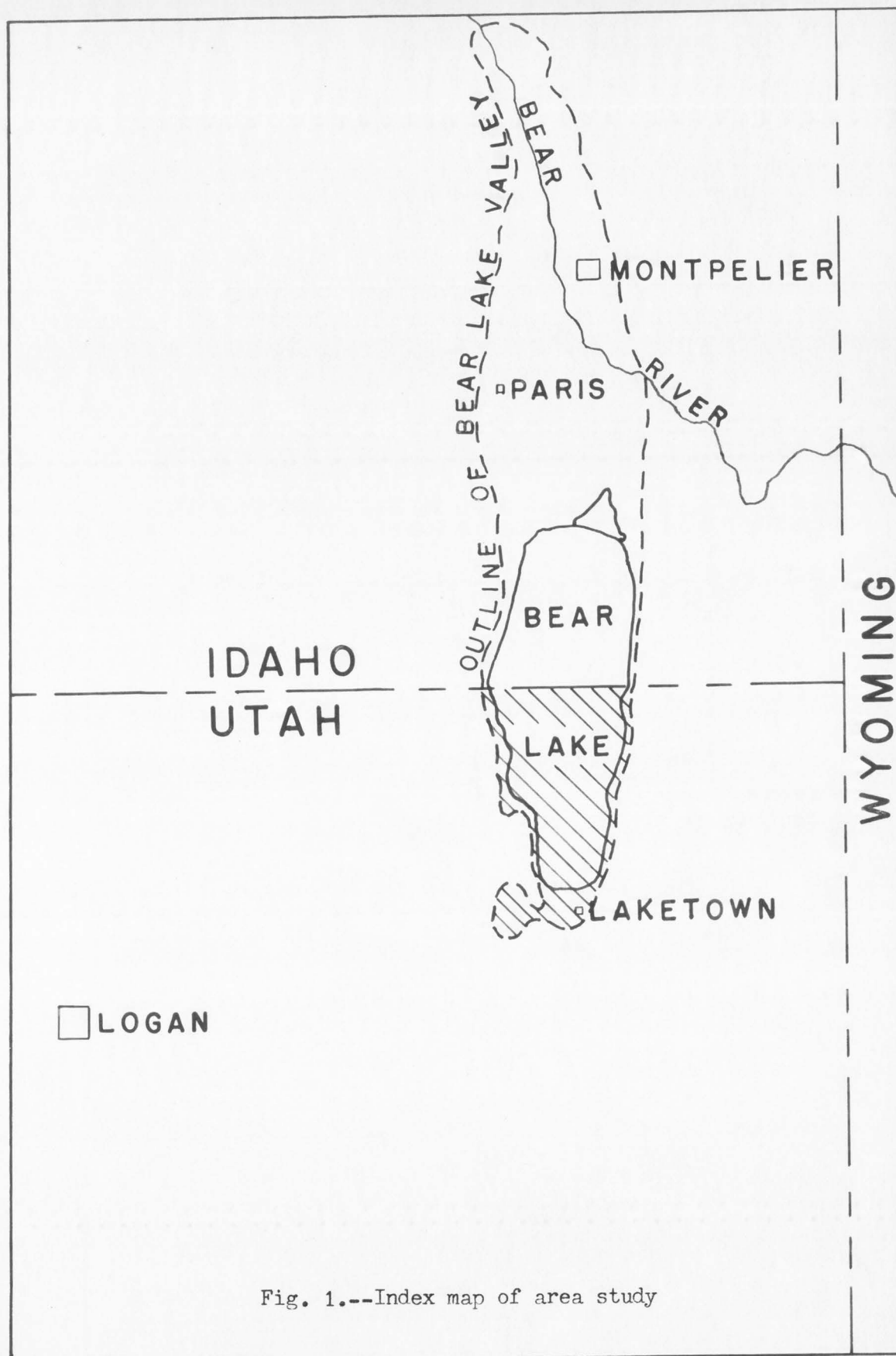


Fig. 1.--Index map of area study

BEDROCK GEOLOGY

General Statement

Bear Lake Valley is situated near the Wasatch line of Kay (1951, p. 14), where the thicker Paleozoic sediments of the Cordilleran geosyncline give way to the thinner sediments of the Wyoming shelf. The thick Cambrian section described by Walcott (1908) outcrops along the western side of the valley in the foothills of the Bear River Range, and although his thickness measurements and description were largely taken from the section in Blacksmith Fork Canyon, such names as Langston, Bloomington, St. Charles, and Nounan came from Bear Lake Valley. The Ordovician formations, Garden City limestone, Swan Peak quartzite, and Fish Haven dolomite were not only named from Bear Lake geographic features by Richardson (1913, p. 406-416), but also have their type sections in the valley. The only Silurian formation of the Rocky Mountain region, the Laketown dolomite, was named by Richardson from exposures in Laketown Canyon at the southeast corner of the valley.

Devonian and Mississippian rocks are exposed in the Laketown Canyon section and in the Bear River Range to the west. The type locality of the Mississippian Brazer formation lies only fifteen miles southeast of the valley in the Crawford Mountains. In the vicinity of Bear Lake the thick basin facies of the Oquirrh formation is replaced by the much thinner shelf facies of the Weber quartzite.

The Permian Phosphoria-Park City formation outcrops southeast, northeast, and northwest of the lake. The Bear Lake Plateau includes a notable section of Triassic and Jurassic rocks in which the Park City

Triassic section of Boutwell (1912) is well represented. Type localities of the Jurassic Twin Creek and Nugget formations (Veatch, 1907) are not far east of the lake in the extreme western Wyoming. Cretaceous rocks are not represented in the drainage area of the valley.

This comparatively thick section of Paleozoic and Mesozoic rocks was deformed by thrusting and folding during the Laramide orogeny. Early Tertiary erosion bevelled these structures and provided the coarse alluvium of the Wasatch group, which apparently once completely blanketed the area of Bear Lake Valley. Later erosion and faulting created Bear Lake Valley, in which the Pliocene Salt Lake group was deposited. Quaternary deposits are the Bear Lake formation and associated sediments.

Stratigraphy

The bedrock stratigraphy of Bear Lake Valley is summarized in the accompanying table 1. In the Bear River Range to the west, the Paleozoic formations, from the Brigham quartzite to the Swan Peak quartzite are folded in the Fish Haven syncline. East of the Bannock overthrust the low hills north of Round Valley, at the southwestern margin of Bear Lake Valley, include the same section, but are largely covered by the Wasatch group.

In the Bear Lake Plateau to the east, the Triassic and Jurassic rocks are tightly folded into anticlines and synclines that were bevelled by the erosion that followed the Laramide orogeny. The surface that truncates them is covered by the nearly horizontal sedimentary rocks of the Wasatch group. In the southeast corner of the valley, south of a major east-west fault, a complete section from the Cambrian St. Charles formation to the Triassic Thaynes formation is exposed.

Table 1. Stratigraphy

System	Series	Group and Formation	Thickness	Lithology and Remarks
Quaternary	Recent	Colluvium and Slopewash		Talus at the base of the steep slopes and fine alluvium basinward from the gentle slopes
	Late Pleistocene	Bear Lake fm.	190	Pebble bars, clay, and fine-grained calcareous sand with abundant shell fragments
Tertiary	Pliocene (?)	Salt Lake gr.	3000	Light-gray conglomerates with a white calcareous matrix, light-brown mudstones, and light-gray tuffaceous shales
	Eocene	Wasatch gr.	300	Red conglomerate and sandstone, boulders of Paleozoic quartzite and limestone Locally beds of limestone shale, and tuff are present.
Cretaceous	Upper	Wayan fm.	7000	Continental sandstones, limestones, shales, and conglomerates
		Bear River fm.	3000	Fissile dark clay and carbonaceous shale with interbedded gray limestone and buff sandstone
	Lower	Tygee sandstone	100	Gray to buff even-grained sandstone
		Draney limestone	175	Gray to white weathering limestone

Table 1 (Cont'd)

System	Series	Group and Formation	Thickness	Lithology and Remarks
Cretaceous	Lower	Bechler conglomerate	1725	Gray and reddish sandstone with interbedded conglomerate
		Peterson limestone	205	Gray to white weathering, massive bedded limestone
		Ephraim conglomerate	1025	Red conglomerate with minor sand and purplish bands of limestone
Jurassic	Upper	Stump sandstone	600	Thin bedded gray sandstone and sandy limestone
		Preuss sandstone	1300	Plane bedded reddish-gray sandstone and siltstone
	Middle	Twin Creek limestone	3000	Medium to light-gray limestone
	Lower	Nugget sandstone	1500	Massive, crossbedded, fine-grained red sandstone
Triassic	Upper	Ankareh fm.	800	Continental shale, sandstone, limestone, and conglomerate
	Middle			
	Lower	Thaynes fm.	2000	Gray limestone, olive-gray calcareous sandstone, and local lenses of shale
		Woodside shale	1000	Red and green shale with minor limestone and sandstone

Table 1 (Cont'd)

System	Series	Group and Formation	Thickness	Lithology and Remarks
Permian		Phosphoria fm.	300	Consists of three members, a lower phosphatic shale member, the Rex chert member, and an upper shale member
Pennsylvanian		Wells fm.	6000	Thick bedded quartzite, calcareous sandstone, and sandy limestone
Mississippian	Upper	Brazer fm.	4000	Massive dark to light-gray siliceous limestone and siltstone. Locally chert nodules are present.
	Lower	Madison fm.	600	Dark to bluish-gray, medium to thin bedded limestone
Devonian	Upper	Threeforks limestone	200	Thin bedded limestone and silty limestone Gives a reddish tint on a weathered surface
	Middle	Jefferson fm.	2000	Massive bedded dark-gray dolomite which weathers to a characteristic brown
Silurian	Middle	Laketown dolomite	1100	Massive light-gray dolomite and dolomitic limestone

Table 1 (Cont'd)

System	Series	Group and Formation	Thickness	Lithology and Remarks
Ordovician	Upper	Fish Haven dolomite	500	Dark-gray, medium bedded dolomite with local lenses of shale
	Middle	Swan Peak quartzite	600	Relatively clean light colored quartzite
	Lower	Garden City fm.	1800	Gray limestone with intraformational conglomerate in the lower two-thirds and cherty beds in the upper third
Cambrian	Upper	St. Charles fm.	1100	Consists of three members, the basal Worm Creek quartzite member, a middle silty limestone member, and a upper dolomite member
		Nounan fm.	1000	Massive light-gray dolomite and bedded limestone
	Middle	Bloomington fm.	1500	Gray to bluish-gray limestone with a basal shale member, the Hodges shale
		Blacksmith fm.	750	Thin to thickly bedded blue-gray limestone
		Ute limestone	750	Medium-gray limestone with partings of shale and siltstone
		Langston fm.	200	Limestone, shale, and dolomite with an upper fossiliferous shale member, the Spence shale
	Lower	Brigham quartzite	6000	Massive beds of buff, gray, and pink quartzite with local lenses of conglomerate

Structure

General statement

In general the structural geology of the region follows the pattern found throughout the Middle Rocky Mountain province. The sharply folded Paleozoic and Mesozoic strata are overturned to the east and locally dislocated into thrust blocks. This indicates thrusting from the west. The overlying Cenozoic rocks truncate the older rocks in a marked angular unconformity.

Laramide structures

Prior to the Laramide orogeny the area of study, being in the Rocky Mountain geosyncline, was mainly a site of deposition. A relatively complete sedimentary sequence from the Cambrian to the Cretaceous is present. At the close of the Cretaceous a large compressional stress developed in a west-southwest to east-northeast direction (Mansfield, 1927, p. 171). The strata from Cambrian to Cretaceous were folded into tight asymmetrical anticlines and synclines. In the Bear River Range the folds are broad and slightly inclined to the east in contrast to the tight asymmetrical folds of the Bear Lake Plateau. Notable among the faults produced during this diastrophic movement is the Bannock overthrust. As mapped by Richards and Mansfield (1912) the Bannock overthrust extends in a rather sinuous trace across Bear Lake Valley in a southwesterly direction. The great irregularities in this trace are due to erosion of the folded overthrust. The overthrust is readily visible northwest of Garden City, Utah, where the Brigham quartzite (Lower Cambrian) is seen to lie against the Garden City limestone (Lower Ordovician). The stratigraphic displacement at this point is approximately 12,000 feet (Richardson, 1941, pl. 1). The trace of the fault southward is largely covered by Tertiary sediments of the Wasatch group, but its

approximate position has been traced by Richardson to the southern margin of the Randolph quadrangle. The fault mapped by Gale and Richards (1910, p. 526) south of the Randolph quadrangle is believed to be the southern continuation of this gigantic overthrust. The northern continuation of this fault is approximately parallel to the valley to the vicinity of Sharon, Idaho, where it is postulated (Mansfield, 1927, p. 158) to cross the valley to the vicinity of Montpelier, Idaho. Several areas of broken and crushed rocks along this trace indicate a zone of thrusting rather than a single plane of overthrust. Thus it is seen that slices of older rocks are successively placed against younger rocks. From Montpelier the trace of the fault continues northward to a point north of Georgetown, Idaho, where it reverses direction and sweeps south and east.

The horizontal displacement of this fault has been postulated as not less than twelve miles with a maximum measured overlap of about thirty-five miles (Mansfield, 1927, p. 158). The length of this fault trace, from Utah northward into Idaho, is about 270 miles.

Tertiary structures

The faulting of Tertiary age is presumably the structural element which formed Bear Lake Valley (Mansfield, 1927, p. 30). The truncated facets of the mountain front extending from south of Dingle, Idaho, to the vicinity of the lake reflect high-angle faulting. The fault continues southward along the edge of the lake and probably terminates in the vicinity of Laketown, Utah. Fathograms of the lake bottom show evidence of this high-angle normal fault extending along the east side of the lake (Williams, personal communication). The steeply dipping scarp-like aspect of the Nugget sandstone adjacent to the lake shore may also indicate high-angle faulting (plate I, fig. 1). The large conspicuous scarp of the Bear Lake fault makes a bold impressive mountain front from the Hot

Springs, at the northeast corner of the lake, to a point south of Dingle where the mountain range has been dissected by the Bear River. The trace of the fault has here been obscured by the alluvium supplied by the river or is the termination of the fault. There is, however, an escarpment west of Dingle which could be the northward continuation of the fault. Mansfield has postulated that the Bear Lake fault may continue northwest from Montpelier to the travertine deposits at the mouth of Three-mile Creek, however, this covers a distance of sixteen miles where the fault, if present, is covered by the valley sediments (Mansfield, 1927, p. 158).

The southern end of the valley also shows evidence faulting. A major east-west fault separates the Paleozoic rocks exposed in old Laketown Canyon from the Nugget sandstone exposed on the north. This fault is believed to be of considerable extent and its intersection with north-south structures on southwestern margin of the valley may have had a bearing on the formation of Round Valley (Richardson, 1941, p. 41).

A high-angle fault was inferred by Richardson (1941) along the extreme southwestern edge of the valley. The trace of this fault lies along the present edge of the lake. An escarpment is shown on the fathograms of this region (Williams, personal communication). Other escarpments noted on the fathograms are shown on the map in the pocket.

Recent faulting

Recent movement coupled with erosion along the Bear Lake fault has obscured shore features of the expanded lake along the eastern side of the present lake. The truncation of alluvial fans is quite conspicuous along the east shore, as shown on plate I, fig. 2. The occurrence of warm springs along the trace of the fault are also evidence of a recent movement. The large deltas extending from North and South Eden Canyons show

prominent escarpments (fig. 2). Although Mansfield and Richardson believed these escarpments to be the edge of former lake terraces the author believes that they are the trace of recent movement along the Bear Lake fault. The rather continuous trace of recent scarplets along this portion of the valley suggests recent activity along the Bear Lake fault. The northern and southern parts of these deltaic deposits, below the escarpment, are considerably lower in elevation than the central part. If the terraces were cut by a former water level plane, one would expect the terraces to maintain a similar elevation. However, if the deltas were faulted, the field relationship could be justified.

The sinuous trace of the scarplets in the alluvium exists almost without break from the south end of the lake to a point just south of Dingle, Idaho. In places it is seen to extend into the lake (map in the pocket). From south of Dingle to the north end of the lake scarplets are noted along the impressive mountain front. Southward, along the lake shore, scarplets in the alluvium are most prominent and the continuity of the trace suggests a reactivation along the older Bear Lake fault. An arcuate pattern of the scarp is seen at Indian Canyon. The vertical displacement of this scarp can only be estimated or averaged from the varying amounts along its trace. At North Eden Canyon the escarpment is about thirty-five feet high. Other displacements along the trace average approximately ten feet.

PLATE I



Fig. 1.--Looking east across Bear Lake Valley at the faceted escarpment along the southeastern boundary of the valley



Fig. 2.--A truncated alluvial fan on the east side of Bear Lake about one mile south of South Eden Canyon



Fig. 2.--A view looking north along the escarpment at North Eden Canyon

PHYSIOGRAPHY

General Statement

The Utah portion of Bear Lake Valley lies between the Bear River Range on the west, and the Bear Lake Plateau to the east. The plateau extends westward past the south end of the valley and merges with the foothills of the range. The valley in Utah is widest at the Idaho line, nearly eight miles, and narrowest at the southern end, three to four miles. It is about fifteen miles long, including the southward extension of tributary Round Valley. From the Idaho line the walls of the valley converge slightly to the latitude of Gus Rich Point. South of this point they are essentially parallel, giving the south end of the lake and the lowland west of Laketown a rectangular outline.

Physiographic Features

The area of the valley may conveniently be divided into several physiographic divisions of importance in the consideration of the surficial geology. These will be discussed separately.

Eastern escarpment

This is the western edge of the Bear Lake Plateau where it is broken by the Bear Lake fault. It is perhaps essentially a fault escarpment. It appears to begin at Laketown with the major east-west fault, and continues northward far past the Idaho line. Its greatest relief is between the Eden Canyons where it reaches a value of some 1,600 feet. From the Idaho line to South Eden the escarpment is in Nugget sandstone; from South Eden to the end of the lake, the Nugget outcrop is underlain by a

narrow exposure of Ankareh shale.

The fathograms indicate that the escarpment continues beneath the lake waters with little change from its subaerial portion. On it have grown the deltas at North and South Eden Canyons. At its southern end the Laketown embayment lies against and buries the lower part of the escarpment.

Lake Basin

The profiles obtained by J. S. Williams with a fathometer, combined with the subaerial portions from the topographic map, show that the lake basin, north of the rectangular southern extension, has an asymmetrical transverse profile, which in effect continues the gentle profile of the east slope of the Bear River Range, and the steeper profile of the face of the Bear Lake Plateau, until they meet at the deepest part of the basin, near the east shore of the lake. This asymmetry presumably is due to the presence and the continued activity of the Bear Lake fault. South of Gus Rich point, where the valley outline becomes rectangular, the transverse profile is more nearly symmetrical being balanced by the fault that appears to be along the point. In detail, the fathograms reveal a remarkably smooth surface on the lake basin, probably due to the activity of turbidity currents.

North Eden delta

This is the delta built in Bear Lake by the creek issuing from North Eden Canyon. Its subaerial portion covers less than one square mile, and the fathogram profiles of the lake indicate that its subaqueous portion is perhaps no greater. The delta is conceived to be a relatively small deposit of stream alluvium clinging to the face of the eastern escarpment. Its size argues for the relative recentcy of the lake basin. Its surface is broken by a recent fault escarpment.

A water well located on the North Eden delta was deepened for A. H. Nebeker, application #A 27359 in section 4, T. 14 N., R. 6 E., from a depth of sixty feet to a depth of 215 feet. The well was logged as follows:

	Internal feet	Total depth
Boulders	60-74	74
Clay	74-76	76
Gravel	76-109	109
Clay	109-112	112
Water gravel	112-215	215

South Eden delta

This delta is closely similar to that at North Eden Canyon in most respects. However, it is not as symmetrical, being extended somewhat to the south, perhaps due to the fact that the escarpment recedes somewhat on that side because of the presence of the Ankareh formation at its base. This delta is also thought to represent a relatively small mass of alluvium lying against the face of the eastern escarpment. Its surface is broken by a recent escarpment which crosses from the north side, but dies out before reaching the south side of the delta.

Laketown embayment

This lowland at the extreme south end of the lake, is created by the alluviation of the end of the lake basin, beyond the area now covered by the lake waters. During the expansion of Bear Lake it was largely covered. It has an area of about four square miles, and a relief of less than fifty feet. It includes some of the best farm land in Rich County. It is separated from Round Valley by a row of low hills. Round Valley Creek flows between these hills and northward across the embayment to the lake.

Round Valley

This is a small elongate valley in the foothills of the Bear River Range, separated by low northwest trending hills from the Laketown embayment. The rather flat floor of the valley has an area of about seven square miles. Round Valley Creek drains most of the area, but the northernmost drainage of Cheney Creek and its tributaries leaves the valley at its northern end through a small valley that enters directly into the lake basin.

Outcrops of the Wasatch group completely surround Round Valley, suggesting that erosion in this relatively weak sedimentary unit may be the origin of the valley. The alluvium and the lacustrine sediments in the valley are thought to be relatively thin. At the expanded level the lake submerged the lowest parts of the valley, entering along Round Valley Creek, and deposited relatively fine lake sediments and extensive masses of tufa.

Gus Rich escarpment

This escarpment along the west side of the lake from Gus Rich point to the south end bounds a ridge of Brigham quartzite covered in part by Wasatch conglomerate. The bathograms indicate that it extends to the lake bottom as does the escarpment along the east side of the lake. This escarpment has a relief of some 700 or 800 feet and it presumably is a fault escarpment, like that on the east.

Pickleville embayment

This small embayment extends southward behind Gus Rich point for about one mile. The area of the Pickleville embayment is little more than one square mile, and the embayment may owe its existence to erosion of the Wasatch group north of the quartzite hills that form the Gus Rich escarpment. During the expansion of Bear Lake it was largely covered by

lake waters which entered from the north, and also through a low pass in Gus Rich point. The lake completed bay bars across both entrances before it withdrew. At lower stages the embayment was well above lake level.

Garden City bench

This bench or terrace along the west side of the valley extends from the Pickleville embayment northward to the mouth of Swan Creek. It appears to be due to the belt of Wasatch group rocks, about one mile in width, which here overlap the older and more resistant rocks of the Bear River Range. The bench appears to be thinly veneered at Garden City and again near Lakota by sediments from Garden City Canyon and Swan Creek respectively. These sediments, and the rocks of the Wasatch group have been reworked, below elevation 5,948 by the waters of Bear Lake. The terrace provides the site for Garden City, and at its north end, for Lakota Resort.

Shore Features of Bear Lake

Examination of the lower slopes of the valley has revealed the presence of three stages of Bear Lake higher than the present stage. These are here termed the Willis Ranch, the Garden City, and Lifton stages.

Table 2. Stages of Bear Lake

	Elevation
Willis Ranch stage	5948
Garden City stage	5938
Lifton stage	5929

Willis Ranch stage

The Willis Ranch stage of Bear Lake is the highest level at which the lake remained for a time sufficient to build shore features. The elevation of these features indicate the water level plane was approximately 5,948 feet or twenty-five feet above the present regulated lake level. The southern boundary of this stage extends into the northern central part of Round Valley. The eastward continuation of the boundary follows the valley margin to a point slightly north of Montpelier, Idaho, where it swings northwesterly up to the outlet below Georgetown, Idaho. The western boundary continues from the outlet through Bern to Ovid, Idaho, where an extensive bay was formed west of Ovid. South from the town of Ovid the western boundary lies along the eastern margin of Paris, Bloomington, St. Charles and along the western margin of the valley in the vicinity of the present lake. The trace of this shoreline in the Utah portion of the valley is shown on the map in the pocket on the back cover.

The Willis Ranch stage is the oldest and highest level which Bear Lake attained during the late Wisconsin glacial stage. The dating of this stage is based on the evidence of glacial activity in the surrounding canyons suggesting a moist climate. The expansion of the lake has left quite continuous shore features around the valley at this elevation. Profiles of the Willis Ranch stage are shown by figure 4. The gradual lowering of the outlet near Georgetown, Idaho, has reduced the lake successively to its present level. Notable interruptions in this lowering have produced two other stages of Bear Lake.

Along the eastern escarpment evidence of shore features at the Willis Ranch level are lacking and it is not unlikely that this is due to recent faulting along this portion of the valley. There are, however,

a few relatively poor and scattered remnants of the Willis Ranch stage along this eastern margin of the present lake. The persistence of shore features at this altitude noted elsewhere in the valley suggests that the features developed at this time, along the eastern escarpment, must have been removed by causes other than normal erosion. The deltas extending from North and South Eden Canyons show only terracing on the north and south extremes of these deposits. The central portions are totally lacking in shoreline evidence at this level. The base of the large escarpment located on the North Eden delta is in a convex form which is not indicative of a water level plane. A similar escarpment is noted on the South Eden delta although it is not tracable in the central portion of the delta. As discussed earlier this feature is suggestive of recent faulting. Thus along the eastern escarpment the shore features of the Willis Ranch stage have probably been destroyed by recent faulting along the trace of the Bear Lake fault.

Within Round Valley which was the southernmost extent of the lake a shallow bay existed. The deposition of much calcareous tufa in this area is indicative of the lake's shallowness here. Actual shoreline evidence is poor within Round Valley and therefore the shoreline was mapped with reference to elevation. The present surface of Round Valley is hummocky; this is probably due to the drainage imposed on the valley by the adjacent canyons.

The Laketown embayment is the site of an extensive bar built during the Willis Ranch stage. This bar extends from below Laketown, Utah, to the southwest corner of Bear Lake Valley. This bar is now occupied by the highway and is shown on figure 3. The bar separated the lagoonal area of the Laketown embayment and the bay region of Round Valley from the main body of Bear Lake during the Willis Ranch stage. The formation of

this bar is indicative of northerly winds. Northerly winds of Willis Ranch time would develop littoral currents along the eastern and western shores. The waves developed by the northerly winds would strike obliquely on the respective shores, as a result of wave refraction, and induce a littoral current shoreward of the breaking point. Approximately eighty per cent of the material moved by wave action is believed to be moved in this region (J. W. Johnson, 1956, p. 2216). The direction of these currents and the direction of the transportation of material would then be in a southerly direction. As these currents approached the southern end of the lake they would sweep around losing their velocity and transporting power. The material deposited would form as spits extending from the eastern and western margins of the valley. The spits joining formed a bar completely across the laketown embayment.

Along the Gus Rich escarpment remnants of wave terracing is seen at the Willis Ranch level. The valley where Cheney Creek empties into Bear Lake was a small bay during Willis Ranch time. The bay extended up the valley approximately 0.25 mile. Gus Rich point, during the Willis Ranch stage, was an isolated point being connected on the south and west sides by bars.

The Pickleville embayment was separated from the main body of the lake by a bar which extends in an east-west direction from Gus Rich point to the town of Pickleville, Utah. The formation of this bar has probably been from northeasterly winds, developing littoral currents along the central western shore, with its main development in a west to east direction. Winds of this nature would supply the greatest length of fetch. Although this bar and the southern boundary bar are indicative of essentially northerly winds, which are the prevailing winds of today, the bar formations on the northern end of the lake indicate that their

formation was from south to northeast. This would necessitate the existence of southerly winds. This, however, is not unlikely as even today winds also come quite often from the southeast and southwest directions even though the prevailing winds are northwesterly (Hambidge, 1941).

The Garden City bench displays wave-cut terracing as a prominent feature of the Willis Ranch stage. South and west of Garden City, Utah, the terrace is well developed in the Salt Lake group sediments of the valley. South of the Lakota resort the terrace, though less developed than at south of Garden City, shows definite shoreline topography.

Garden City stage

Above the present level of the lake and at an elevation of 5,938 feet are the remnants of another stage of Bear Lake. It is here termed the Garden City stage because of its good development in the vicinity of Garden City, Utah. Along the shoreline of this stage are fine examples of bars, spits, wave-cut terraces, and numerous minor features of shoreline development. The Garden City shoreline extends around the present lake on the east, west, and south sides in a relatively close proximity to the present shoreline. North of the lake this stage follows essentially the valley boundaries. The northeastern boundary is seen to traverse through Montpelier, Idaho, and commence a northwestwardly trend approximately two miles north of Montpelier. Large alluvial fans have here forced the shoreline basinward. This northwestwardly trend continues to the outlet below Georgetown, Idaho. The northwestern boundary lies just east of Bloomington, Paris, and Bern, Idaho. This trend continues on northward to the outlet. The area encompassed by the Garden City stage is approximately 210 square miles.

In the area covered by the eastern escarpment the shoreline evidence of this stage is largely lacking. Only scattered remnants of shoreline



Fig. 3.--The south end of Bear Lake Valley. View looking east on Highway 3 which is located on the Willis Ranch bar. Laketown, Utah, is in the distant center of the photograph.

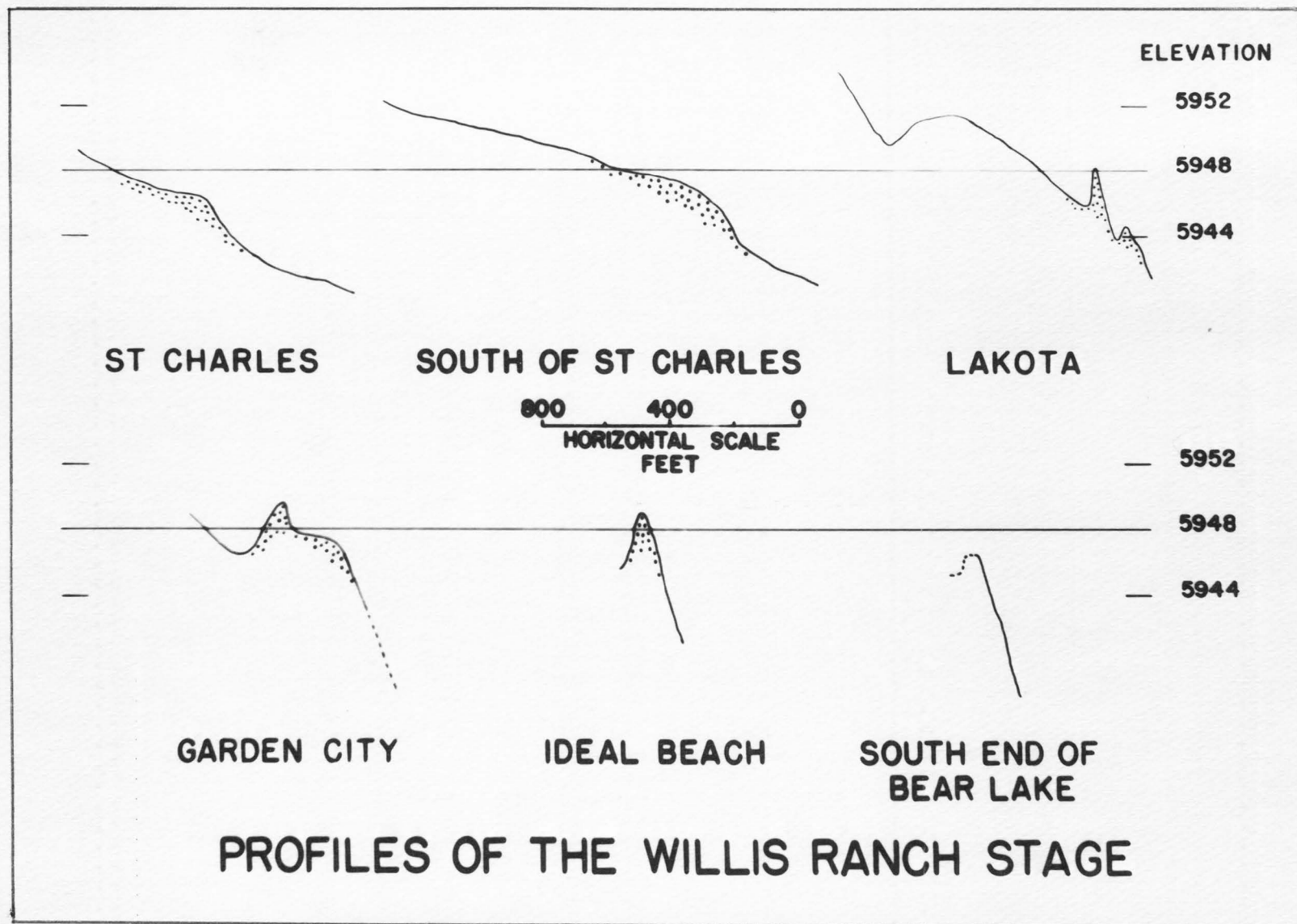


Fig. 4

features are observable at the altitude of the Garden City stage in this area. The deltas at the mouths of North and South Eden Canyons are lacking in features indicative of a water level plane at this elevation. From the profiles made at the extreme north and south ends of these deltas possible wave terracing could be deduced at the Garden City level (figure 6). However, this feature is not traceable around the fronts of the deltas. Therefore, if the hypothesis of recent faulting is accepted, an explanation for the lack of field evidence along the eastern escarpment is possible. If faulting has occurred after the Garden City stage, the shoreline remnants may have been almost completely obliterated.

Within the Laketown embayment several well defined bars formed during Garden City time. These bars curve around the southern end of the valley in much the same pattern as the present shoreline. The steeply dipping hogback of Nugget sandstone seen along the eastern escarpment supplied much material to the littoral currents prevailing during Garden City time. There were three bars formed within the Laketown embayment during the Garden City stage of Bear Lake. Of the three bars the northernmost bar is almost exclusively built of Nugget sandstone pebbles for approximately two-thirds the extent of the bar. The other third of the bar, on the western end, is made up of primarily quartzite and limestone pebbles. This indicates that spits grew from both sides of the lake, the eastern spit being longer. The joining of these spits formed the existing bar. The lack of fine-grained material on the surface of this bar is probably due to eolation. The other bars located south of this bar are topographically as prominent but lack the exposure of the northernmost bar due to a vegetative cover (figure 5). Numerous pebbles found along their course do however indicate a similar formational history. The occurrence of several bars at Garden City elevation indicates

a low gradient prevailed on the southern beach during this stage. As the first or most southerly spits grew and ultimately joined forming a barrier bar across the Laketown embayment the next successive pair of spits began to form. This process then repeated itself until the three bars had been formed. Thus the relative age of these bars increases from north to south. It is not unlikely that the prevailing winds of Garden City time were from a northwesterly direction, as they are today. This would supply a maximum length of fetch and also obliquely breaking waves for the formation of littoral currents along the eastern and western shores. The longshore drift of material, as discussed above, is a prominent method of transportation for shore sediment (Johnson, 1956). Therefore, during Garden City time much material was moved along the southeastern and southwestern margins of the lake to supply the growing spits.

Along the Gus Rich escarpment a few remnants of wave terracing are located. The steep drop of the beach face and the resistive Brigham quartzite, outcropping in this region, explain the general lack of shore features. A prominent wave-cut terrace was formed during Garden City time where Cheney Creek empties into Bear Lake. The terrace was here formed in the alluvium supplied by the creek.

Extending across the Pickleville embayment from Gus Rich point to Pickleville, Utah, is an extensive bar built during the Garden City stage. This bar is made up of medium-grained quartz sand. The formation of the bar has probably been from west to east. It follows essentially the same pattern as the Willis Ranch bar in this area. Here again northerly winds seem to be the most probable mode of formation. They would sweep across the greatest expanse of water and develop a littoral current along the southwestern shore. Figure 7 illustrates the formation and direction of the littoral currents. A wave-cut terrace is noted at

this level along the lower portion of Pickleville, Utah, and several homes have been located on the terrace.

Along the Garden City bench wave terracing is the prominent shore feature. In the southern limits of Garden City, Utah, the terrace is quite pronounced and the highway has been built along it in this section. Northward from Garden City to the Utah state line terracing is the predominant feature of this stage. A notable example of this terracing is seen at a point just south of the Lakota resort.

Lifton stage

The Lifton stage of Bear Lake is the most recent stage at which the water level was above the present lake level. The altitude of this water level plane was 5,929 feet; this is approximately six feet above the present lake level. The Lifton stage was named for the prominent bar enscripting the northern end of the lake. Located on this bar and regulating the water level of the present lake is Lifton Pumping Station, owned and operated by the Utah Power and Light Company. The formation and significance of this bar is discussed by Verlyn Parker (1959).

The east, west, and south boundaries of this most recent shoreline lie within close proximity of the present shoreline. The northern extent is an irregular boundary approximately five miles north of the present shoreline. Several outlets have been observed along this northern boundary of the Lifton stage. It is quite possible that this characteristic might indicate a fluctuation of the lake at this level. If the water level plane dropped from the Lifton level and again rose to that level, a new outlet might have been formed in a different position. However, it is not possible to determine from the field evidence the relative ages of these outlets. No other indications of an oscillatory nature of this stage have been observed. So it may only be postulated



Fig. 5.--The southern end of Bear Lake Valley
showing the prominent Garden City bars

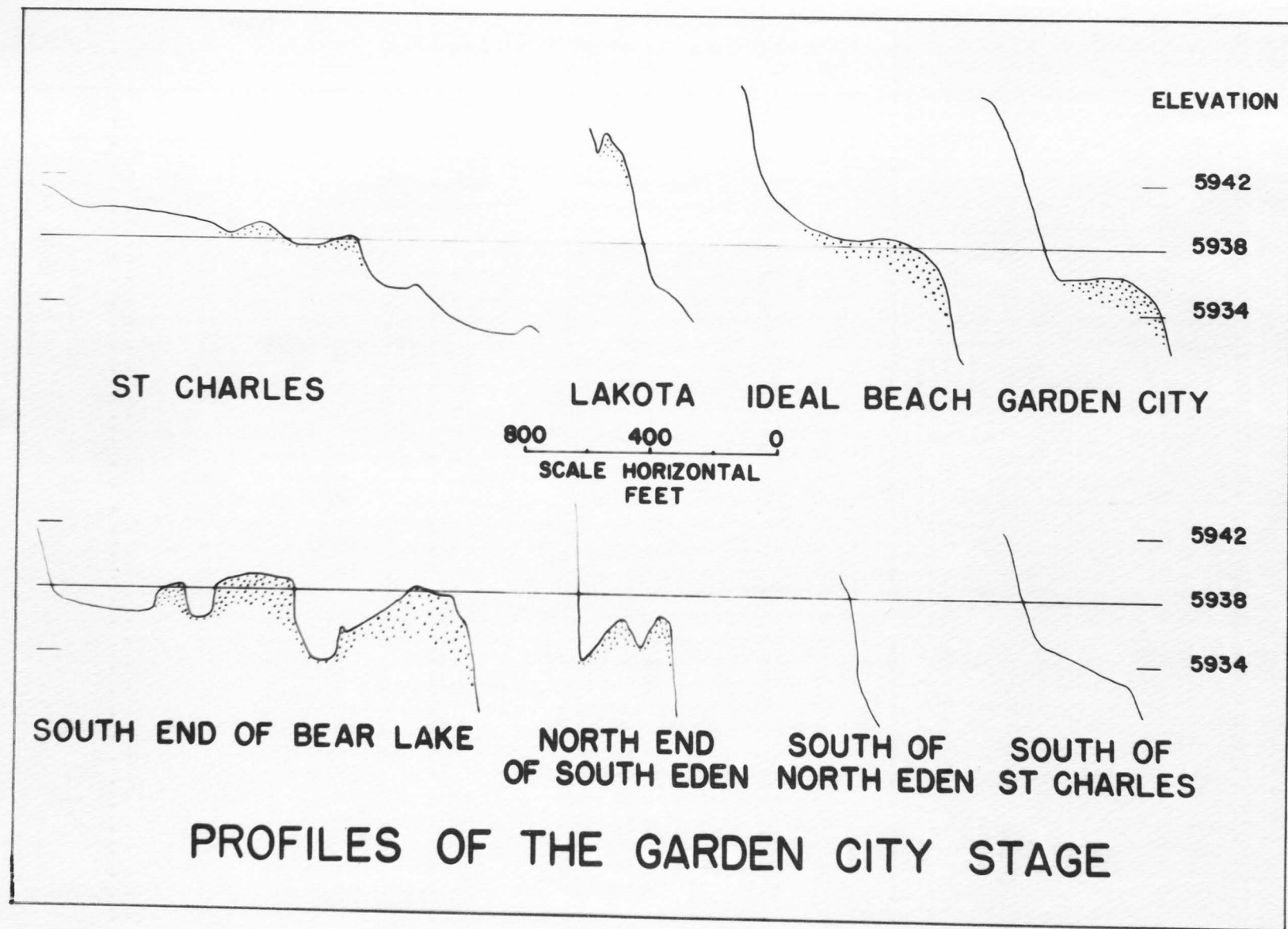


Fig. 6

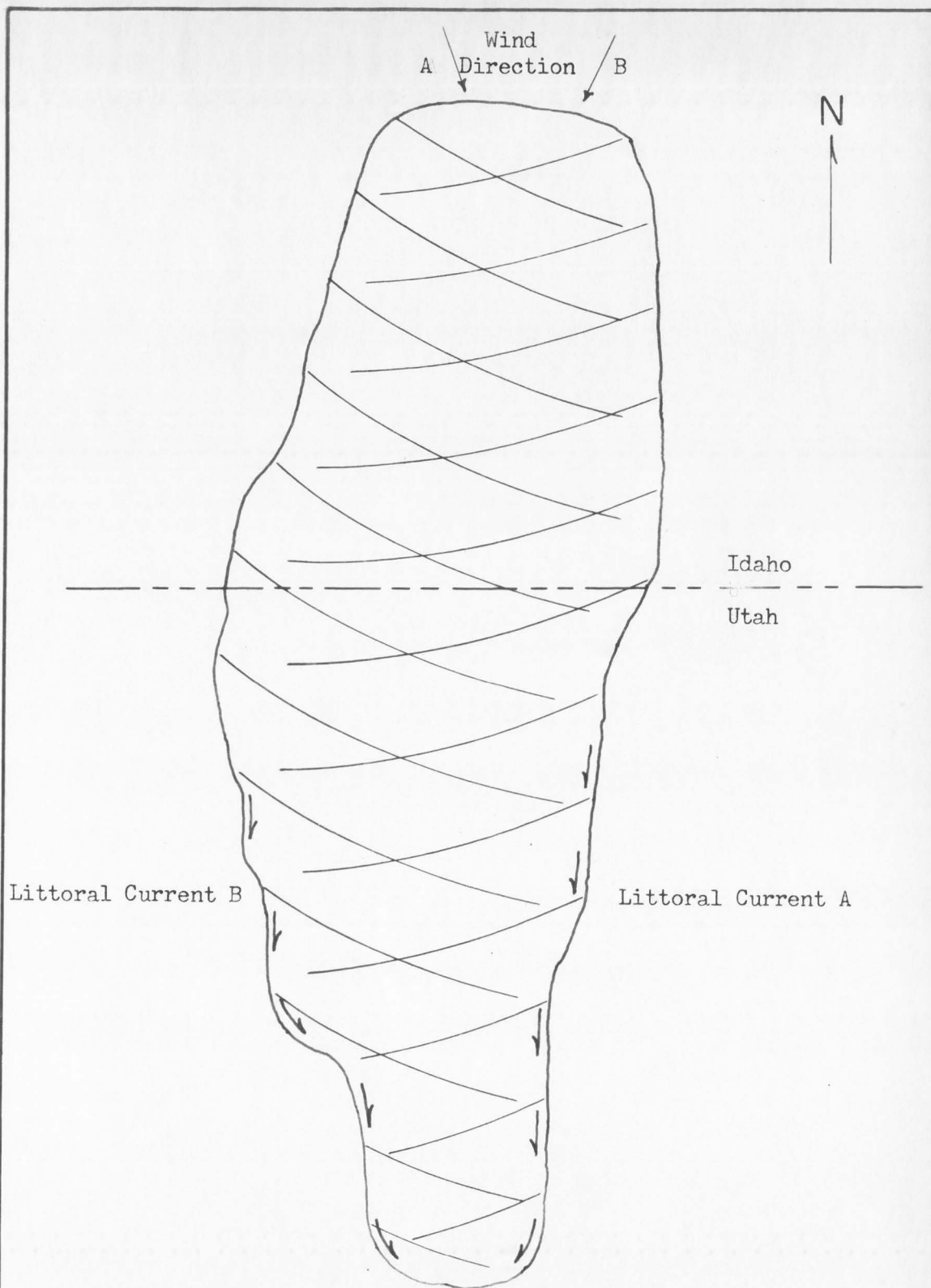


Fig. 7.--Diagram illustrating the direction of beach drifting

that the Lifton stage could have fluctuated at this level.

The eastern escarpment is characterized by a prominent wave-cut terrace at the Lifton level. This terrace lies about two feet above the present storm beach. It is readily visible on the profiles made in this region (figure 9). The general lack of bar formation in this area is probably due to the steep incline of the lake bottom. This is shown on the fathograms of the lake (Williams, personal communication). This relative steepness of the beach face forced the breaker line very close to the shore, thus diminishing its power of bar formation. However, bars are noted along the north and south ends of the North and South Eden deltas. These deposits have undergone wave action during the Lifton stage. A littoral current along the eastern shore would supply sufficient power for the building of these structures from the longshore drift of material. The prevailing winds of the present are from the northwest, and it is not unlikely that this was the predominant direction during the past; under conditions such as these the littoral current would be produced. This fits very well with the formational design of the features discussed in the other stages. The occurrence of the shoreline features along the deltas indicate that the Lifton stage was post recent-faulting in Bear Lake Valley. The road along the Eastern escarpment from south of North Eden Canyon has been primarily constructed on the wave-cut terrace of the Lifton stage.

Within the Laketown embayment the extent of the Lifton stage follows around the present lake in much the same pattern as the present shoreline. A bar, with an accompanying lagoon, is the main topographic feature of this stage in this area. This is shown by figure 9. The formation of this bar is also in agreement with the northerly wind hypothesis. It would supply a maximum length of fetch for the waves.

The littoral currents developed under these conditions would sweep around the southeast and southwest corners of the lake and thus supply large amounts of material to the formation of spits in this area. Probably the spit forming on the southwestern corner of the lake was of a smaller size than the opposing southeastern spit. The size these may only be inferred for the Lifton stage, but as was pointed out earlier this was the formational history for the Garden City bars in this region. These spits finally joined forming the present bar with an accompanying lagoon on its shoreward side. The material of the bar is a medium-grained quartz sand which is coated with calcium carbonate. The carbonate commonly contains a dark organic stain; however, the dark grains are not in sufficient quantity to alter the overall brown color of the sand. In the lagoonal region wind action has modified the ideal picture. Small dunes and irregular bars of fine quartz sand are located along the shoreward margin of the lagoonal region. These eolian deposits contain numerous blowouts.

Along the Gus Rich escarpment the Lifton stage is characterized by a wave-cut terrace. The highway has been built along this terrace from Gus Rich point to the southwest corner of the lake. The beach face here drops steeply as is shown on the fathmograms of the lake (Williams, personal communication). Richardson (1941) has an inferred normal fault along this section of the lake which is in total agreement with the interpretation of the fathmograms. Thus shore features such as bars and spits might not be expected to form under these conditions. Northward from Gus Rich point the lake bottom maintains a relatively gentle grade which is conducive to bar and spit development.

In the Garden City bench region the Lifton stage has developed characteristic shore features. Below Garden City, Utah, a bar and lagoon

are noted at the Lifton stage elevation. These are shown on figure 8. The lagoonal portion has here been overgrown and the topographic effect has been somewhat reduced. Although this bar and lagoon are not everywhere observable along this portion of the shoreline, there is sufficient wave terracing at this level to warrant its adoption as the Lifton stage remnants.

Bear Lake

Along the eastern escarpment no large shoreline features are presently forming. The relatively steep incline of the beach face in this region would account for the lack of shoreline features. Small irregular bars are however seen on the southern shores of the deltas at North and South Eden Canyons. The present shoreline on the south end of the lake, in the Laketown embayment region, is essentially in an east-west direction with no great irregularities. No presently forming spits are seen in this region; the higher stages of the lake which had such prominent bars developed in this area owe their existence to the irregularities of their shorelines. The present beach face in this region is a gently sloping sandy beach. Along the Gus Rich escarpment minor irregularities in the shoreline have small spits developing in a southward direction. This indicates that prevailing littoral current today, in this region, is in a southerly direction. The gently sloping sandy beach of the Pickleville embayment has no presently forming shore features. In the Garden City bench region the currently forming shore features are small irregular bars and spits.



Fig. 8.--The bar and accompanying lagoon of the Lifton stage located east of Garden City, Utah. The topographic effect is somewhat obscured by the vegetative cover.

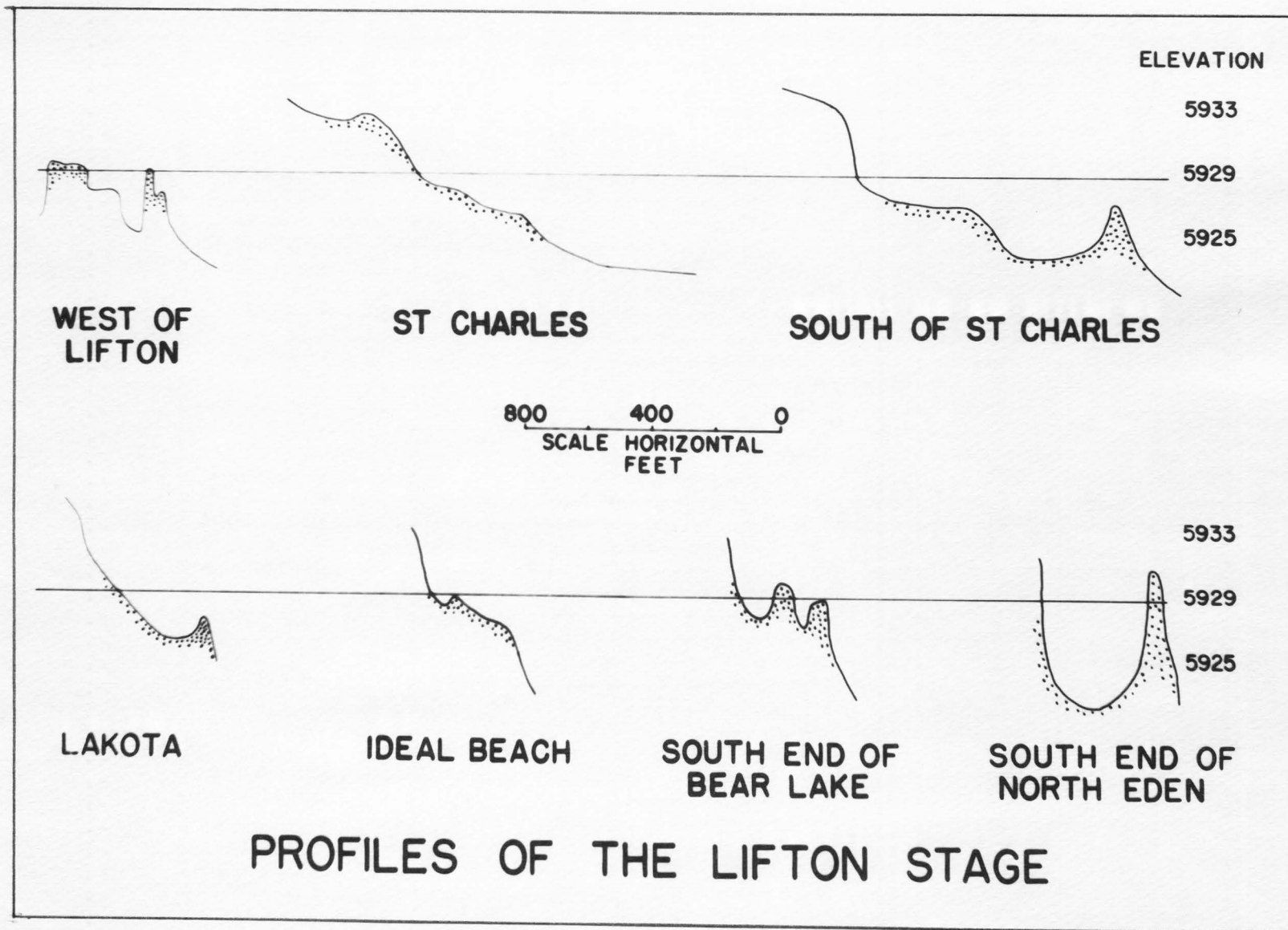


Fig. 9

Hydrography of Bear Lake Valley

Climate

The climate of Bear Lake Valley is semiarid, with an annual rainfall of 9.9 inches. The water supply for the valley is principally from the Bear River, its tributaries, and several large springs located in the adjacent canyons. This is supplemented by a relatively shallow water table in the valley from which many shallow wells are drawing. Two U. S. Weather Bureau gaging stations are located within the valley, one at Montpelier, Idaho, and the other at the Lifton Pumping Station. Climatological data (Reichelderfer, 1926-55) from the Lifton station is presented in the appendix of this paper. Its geographic location, in essentially the center of the valley, and its greater length of record present a general summary of the climate.

The mean annual temperature of the valley is low, approximating forty degrees Fahrenheit. The growing season is short and there are extreme changes in the temperature between day and night and summer and winter. The annual temperatures and average amount of evaporation from April to October are compiled in the appendix.

Stream flow

The Bear River which enters the valley at Dingle, Idaho, follows a meandering course northward through the valley. The river flow is controlled below Dingle, where in the spring it is diverted by means of a canal and made to flow into the Bear Lake. Later in the summer months water is released from the lake to replenish the ebbing Bear River. The water of the Bear River is used for irrigation and the development of electric power. Bear Lake's actual tributary drainage is approximately 250 square miles; however, supplied as it now is with the controlled inlet from the Bear River, the drainage area is increased to about 3,000

square miles (Richardson, 1941, p. 51).

Several large tributary streams to Bear Lake issue forth from the canyons of the Bear River Range. Notable among these is the Swan Creek which is located about 3.5 miles north of Garden City, Utah. It is headed by a large spring about one mile west of Bear Lake which emerges from a cavern in the Blacksmith formation. Its flow as measured by the Utah Power and Light Company is about thirty to thirty-five second-feet in the winter and more than 200 second-feet in May (Richardson, 1941, p. 51). Streams of comparable size occur in Bloomington and Paris Canyons and apparently emerge from solution channels within the Bloomington formation (Mansfield, 1927, p. 316). The eastern boundary of the valley, from Dingle south along the lake shore, is marked by numerous warm springs. A swimming pool located on the northeast corner of the lake utilizes the warm water from the springs for the pool. The temperature of the water as measured by Mansfield (1927) is about 119 degrees Fahrenheit. It is characterized by a hydrogen sulfide odor and deposits of free sulfur are seen on the rocks over which the water flows.

SURFICIAL DEPOSITS

General Statement

In general, the surficial deposits exposed in the Utah portion of Bear Lake Valley are meager. In this regard the valley appears to be rather young, with little time for the accumulation of mantle, at least in the subaerial part. It is proposed to discuss the surficial deposits in two parts: (1) Mantle other than lake deposits and (2) those deposited by the waters of the lake. The sediments deposited by the waters of Bear Lake, both at its higher stages and at the present stage will be called the Bear Lake formation.

Mantle Other Than Lake Deposits

Alluvial fans

Two of the largest alluvial fans in the area occur side by side, and coalesce each with the other, in the southeastern corner of the Laketown embayment. One was produced by the stream from Old Laketown Canyon, the other by the stream from New Laketown Canyon. The village of Laketown occupies the former.

Two successful wells have been drilled in the fan at Laketown, the logs are not available to the writer, but each is several hundred feet deep and penetrates beds of good water-yielding qualities.

The fact that these fans are at least 300 feet deep and of no great real extent, suggests that the valley of Bear Lake has deepened continuously in recent geologic time.

Toward the deeper parts of the valley, the fans are thought to inter-finger with the sediments of the Bear Lake formation.

A rather large alluvial fan has been graded by the creek from Garden City Canyon across the bench at the village of Garden City. It covers an area of nearly one square mile, but appears to be thin, barely covering the Wasatch rocks which compose the bench. With no place on the bench for the deep accumulation of alluvium, the load from Garden City Canyon must largely have been carried across the bench, and deposited in deeper parts of the basin, now below lake level.

Small alluvial fans may be seen at the mouths of the gullies and small canyons along the eastern escarpment. They consist almost entirely of fragments of Nugget sandstone, and round stones from the Wasatch conglomerate that caps the Bear Lake Plateau.

Slope wash

Low on the slopes of the valley sides, particularly about the Pickleville and Laketown embayments, and Round Valley, an appreciable area is covered by fine alluvium carried to the base of the slope by rills and sheet wash. This material grades laterally into distinct alluvial fans at the mouths of the principal tributary canyons, and valleyward into the Bear Lake formation.

Bear Lake Formation

The sediments associated with Bear Lake are here called the Bear Lake formation. This study has not revealed the full extent of this formation, because the test hole drilled in the Lifton Bar at the north end of the lake did not reach the underlying material. For the most part the information obtained has come from an examination of the deposits of the lake at its earlier stages. No cores have yet been obtained from

the lake bottom.

A test hole drilled in the Willis Ranch or Garden City bars of the Laketown embayment would have been most desirable, but was not permissible with the drilling equipment available in the spring of 1959. Therefore, the test of the formation was made on the Lifton bar at the north end of the lake just east of the old outlet channel at the south side of the road. The various facies of the formation will be discussed under the headings bar facies, lagoonal facie, and lake bottom facies.

Bar facies

The formation of bars during the expansion of Bear Lake are primarily the result of longshore drift. In the southern end of the valley prominent bars of all three stages were formed. The Willis Ranch and Garden City bars from east to west, are composed of red Nugget sandstone pebbles for approximately two-thirds of their length. The remainder of these bars consist of a mixture of sandstone, quartzite, limestone, and dolomite pebbles. Varying amounts of medium-grained quartz sand are also seen in these bars. The Lifton bar in this area is composed of medium-grained quartz sand. Approximately thirty per cent of these grains have a dark organic stain, however, this does not modify the overall brown color of the bar. The Willis Ranch and Garden City bars developed in front of the large bay behind Gus Rich Point are composed of clean medium-grained quartz sand.

A well drilled in April 1946 by Mr. Elijah C. Willis, application 17,522 on the Willis Ranch bar in sec. 25, T. 13 N., R. 5 E., is 100 feet deep and penetrates a succession of sediments that appear to represent the bar facies of the formation. Following is the log of this well.

	Internal Feet	Total Depth
Gravel	0-11	11
Sand	11-55	55
Gravel	55-63	63
Clay	63-85	85
Gravel	85-97	97
Clay	97-100	100

The test hole on the Lifton bar at the north end of the lake was drilled just south of the road and east of the old lake outlet channel in SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 17, T. 15 S., R. 44 E. Boise base and meridian.

Following is the log:

Test Hole A

- 0-2 feet. Dark-gray silt with rounded quartz grains. Grains coated with calcium carbonate. Few shell fragments.
- 2-3 feet. Light-gray, subangular quartz grains coated with calcium carbonate. Numerous shell fragments.
- 3-5 feet. Light-gray silty clay with some shell fragments.
- 5-9 feet. Dark-gray, fine, rounded quartz grains with some shell fragments.
- 9-20 feet. Light-gray to pinkish-gray, very fine, angular quartz grains.
- 20-25 feet. Light-gray silty sand.
- 25-35 feet. Grayish-pink sandy silt.
- 35-71 feet. Light-gray to grayish-pink clay.
- 71-79 feet. Light-gray, very fine, angular quartz grains, coated with calcium carbonate. Minor amounts of dark hornblende (?) grains.
- 79-94 feet. Light-gray clay cemented with calcium carbonate. Shell fragments from 90-94 feet.

94-95 feet. Light-gray, very fine quartz grains coated with calcium carbonate. Some shell fragments.

Both of these holes appear to show long-continued deposition of lacustrine sediments of the type now accumulating at the lake shore. This would only be possible with a continuously sinking basin, and argues for the diastrophic origin of Bear Lake Valley.

Lagoonal facies

Lagoons of considerable extent existed in Round Valley and in the Laketown and Pickleville embayments during the Willis Ranch stage of the lake. Presumably relatively fine sediments accumulated in the shallow water behind the bay bars. Tests of these sediments exist only in the logs of water wells drilled in these areas.

One such is the well of Parnell Johnson, application #A 22794 in sec. 4, T. 12 N., R. 5 E., which was logged as follows:

	Internal Feet	Total Depth
Black soil	0 - 4	4
Yellow Clay	4 - 7	7
Gravel	7 - 10	10
Yellow Clay	10 - 21	21
Red Clay	21 - 45	45
Sandrock, hard, brown	45 - 56	56
Sandrock, soft, red	56 - 79	79
Sandrock, medium hard, red	79 - 110	110
Red Clay	110 - 117	117
Hard rock	117 - 130	130
Red Clay	130 - 134	134
Sandrock, hard, brown	134 - 151	151

This well is considered to have entered the bedrock at forty-five feet. Above this position is forty-two feet of five sediments with a single thin gravel layer.

Lake-bottom facies

The sediments on the bottom of the existing lake have not been sampled in this study. Fathograms show that over much of the lake bottom they exceed thirty feet in thickness. Presumably they are fine-grained, watery materials to this depth. Their examination awaits cores taken from the lake bottom. These sediments are thought to have been distributed over the lake bottom, in part at least, by turbidity currents originating in the shore zone of the lake.

GEOLOGIC HISTORY OF BEAR LAKE VALLEY

Tertiary History

The geologic history of Bear Lake Valley involves both structural and erosional elements. Remnants of former erosion surfaces surrounding the valley suggest strong erosional influence in the formation of the valley. Mansfield (1927) has studied the geology of southeastern Idaho quite extensively. He has recognized in this area several erosional periods or cycles and has incorporated them into the history of the region. The linear aspect of the valley boundaries coupled with definite fault evidence indicate some structural control in the valley's geologic history. The major deformation involved in the formation of the valley was in Miocene time and is therefore related to the Basin-Range type development. Hence, erosion controlled by structure constitutes the principal element in the history of Bear Lake Valley.

Pre-Wasatch erosion

The erosion surface upon which the Wasatch formation was deposited is one of the major unconformities in the region. The surface has been developed on the folded Mesozoic and Paleozoic rocks. This surface is rather irregular, and the altitude may vary as much as a few hundred feet within limited areas (Richardson, 1941, p. 5). Two profiles showing this surface indicate that the range of maximum relief at this time was 1,350 feet (Mansfield, 1927, p. 13). The deposition of the Wasatch formation marked the close of this erosion.

Post-Wasatch erosion and deformation

The order of events following the deposition of the Wasatch formation

is vague, but erosion and deformation seem to have been the predominant episodes. However, the deformation of this time probably only interrupted the erosional sequences, as the first notable disturbance was not until middle Miocene. The area of Bear Lake Valley was at that time merely a portion of the extensive peneplain developed on the Wasatch beds. This has been referred to as the Snowdrift peneplain; the top of Snowdrift mountain, northeast of Bear Lake Valley, is thought to retain a portion of this peneplain.

Tygee erosion

The entire Cordilleran region suffered crustal deformation in the Miocene (Blackwelder, 1914). Although the period prior to this deformation is blank, it may be assumed that the broad peneplain of post-Wasatch time was greatly uplifted (Mansfield, 1927, p. 15). It was in this time of deformation that the normal faulting of Bear Lake Valley probably occurred. The remaining time of Miocene and early Pliocene was marked by erosion and the broadening of the now existing valleys. It is essentially here that the history of Bear Lake Valley begins. This erosion and excavation of the valley left the surface upon which the Salt Lake group was deposited. The deposition of the Salt Lake group was a period of aggradation in which the coarse conglomerate facies of the group was deposited. This blanket may have largely filled the then existing valley of Bear Lake as remnants of the Salt Lake group are seen at elevations of 7,850 feet west of Bear Lake Valley in the Bear River Range. At the close of the deposition of the Salt Lake group there may have been some deformation as in many places the rocks of the group are dipping steeply; however, these dips may have been formed by later crustal disturbances.

Gannett cycle

Below the elevation of the Snowdrift peneplain lies a surface which has been named the Gannett erosion surface because of its development in the Gannett Hills, east of Bear Lake Valley. This surface is seen to reach its maximum altitude in the Gannett Hills at about 8,300 to 8,600 feet (Mansfield, 1927, pl. 13). The excavation of the valleys, which were filled with the Salt Lake group, now began with the development of relatively broad shallow valleys. The development of the present drainage pattern dates from this time; thus the Bear River began its course of super position along its present path (Mansfield, 1927, p. 16).

Elk Valley cycle

The development of broad, shallow valleys below the Gannett erosion surface is noted in this cycle (Mansfield, 1927, p. 16). These valleys are superimposed on the valleys formed in the Gannett cycle. The easily eroded Salt Lake group, which filled the valleys of Tygee time, allowed the excavation of these broad, shallow valleys with relative ease. Thus Bear Lake Valley, filled as it was with the Salt Lake group, gave way to a broad relatively shallow valley in the Elk Valley cycle. The remnants of this surface are shown on the west side of the valley above Paris, Idaho. They are the upper rather flat topped foothills of the Bear River Range. The surface as shown by Mansfield (1927, pl. 10) on a profile of Bear Lake Valley gives the altitude at about 6,600 feet.

Dry Fork cycle

At approximately 300 feet below the Elk Valley surface lies another terrace called the Dry Fork erosion surface. The stage of physiographic development of this terrace as described by Mansfield is that of late maturity. Thus the valleys from the Gannett cycle through the Dry Fork cycle have successively cut through the Salt Lake sediments and formed

valleys each of smaller and smaller area. In the vicinity of Paris, Idaho, the lowermost foothills show evidence of a former terrace and are probably the remnants of the Dry Fork cycle. The close of the Dry Fork cycle was marked by a regional uplift (Mansfield, 1927, p. 17).

Blackfoot cycle

The uplift at the close of the Dry Fork cycle allowed the streams to cut deeply and form rather steep-sided canyons. This is one of the three episodes recognized by Mansfield (1927) in the Blackfoot cycle. This is canyon cutting. The Bear River encised its course in the easily eroded valley fills and also in part on the older harder rocks. Bear Lake Valley in this episode probably experienced continued excavation of the Salt Lake sediments, thus increasing its depth and breadth. Following the period of canyon cutting, in which the streams were continually degrading their valleys, came climatic variation which caused the streams to begin to aggrade their valleys (Mansfield, 1927). This relatively arid climate gave birth to large alluvial fans from the canyon mouths. A notable product of this aggradational episode is the large pediment which extends from below Georgetown, Idaho, in the Montpelier quadrangle, westward across the valley. The filling of the former gorge cut by the Bear River with alluvial material from this extensive pediment was proposed by Mansfield (1927, p. 32) as the dam for the expansion of Bear Lake. Bear River is now seen cutting transversely across the outer limits of the pediment.

This episode of aggradation was followed by a period of relatively moist condition which is termed by Mansfield as the St. Charles glacial episode. It was in this episode that Bear Lake advanced to its maximum level and was progressively lowered as the outlet was cut. A glacier, from which the episode received its name, advanced down St. Charles

Canyon and left a rather fresh terminal moraine across the valley floor approximately 7.5 miles from the canyon mouth. This glacial episode is probably of late Wisconsin age (Mansfield, 1927, p. 32). From this period of moist conditions the climate has gradually returned to a more arid state although not approaching that of the aggradational episode.

Formation of the Lake Basin

The formation of the lake basin is dominantly of structural origin. The evidence of recent faulting, which has been previously discussed, suggests a structural origin of the lake basin. The essentially straight sided southeastern and southwestern boundaries of the present lake have small alluvial deposits along their margins. The deltas extending from North and South Eden Canyons, though their subaqueous extent is not known, are small in comparison to the size of the lake. Therefore, from the evidence of recent faulting and the general lack of surficial deposits along the southeastern and southwestern margins of the basin a structural formation of the basin is favored. The structural features of the southern margins of Bear Lake Valley indicate a differential lowering of the valley block, in a north-south direction, producing the lake basin.

History of the Outlet

The expansion of Bear Lake necessitated a dam across the north end of the valley at the gorge incised by the Bear River. Mansfield (1927) proposed that the large pediment which extends across the valley below Georgetown, Idaho, provided the dam. The alluvial material of the pediment has formed a rather thin cap on the underlying Tertiary beds west of Georgetown. Several gravel pits and railroad cuts reveal the feature in this vicinity. The valley of Bear River now cuts across the outer

extremities of these alluvial deposits and has cut through the weak Tertiary beds and even into the resistive Triassic limestone. It was proposed by Mansfield that during the excavation of the valley the Bear River began its course across the Triassic rocks eventually cutting a path through them to account for the great depth of excavation of the valley. Following the excavation of the valley the climate became considerably more arid producing the aggradational episode of the Blackfoot cycle. During this episode the pediment below Georgetown was graded across the valley. The alluvial material filling the gorge which was cut by the Bear River formed the dam for the expansion of Bear Lake. The climatic conditions which prevailed during the St. Charles glacial episode, of the Blackfoot cycle, expanded Bear Lake.

The outlet for the expanded lake was superimposed upon the old course of the Bear River. The gradual lowering of the outlet may have been interrupted by superposition on the Triassic limestone ledges of the former gorge. Such a ledge is seen in the $SE\frac{1}{4}$ $SW\frac{1}{4}$ sec. 11, T. 11 S., R. 43 E, in the Montpelier quadrangle. The approximate elevation of this ledge is 5,950 feet (Mansfield, 1927, p. 32). This is about the elevation of the Willis Ranch stage. The interruptions produced must have been sufficient to build the existing shore features seen at the two lower stages, according to this hypothesis.

The pediment west of Georgetown, Idaho, which is now well dissected by streams and which extends up to the present gorge of the Bear River suggests the foregoing hypothesis. The extensive lava flows which occurred late in Tertiary time in the southern part of the Slug Creek quadrangle, north of the Montpelier quadrangle, do not approach an altitude capable of damming the expanded Bear Lake. The flows noted at their southern limits, approximately three miles north and west of Georgetown,

reach only an elevation of 5,922 feet, which is only about the elevation of the present lake (Mansfield, 1927, p. 32).

The tectonically active setting of Bear Lake Valley may lend support to a tectonically produced dam. The unquestionable evidence of faulting along the southeastern boundary of the lake and the linear aspect of the extreme southwestern boundary suggest a structural lowering of the southern portion of the valley. The valley block may have been lowered in a differential fashion, in a north-south direction, with the "hinge" located in the northern boundary of the valley in the general region of the outlet. That this has taken place since the deposition of the Salt Lake group is suggested by the evidence of recent faulting. As the valley was formed prior to the deposition of the Salt Lake group the accumulating weight of the Salt Lake sediments may have produced a reactivation on the bounding faults. From the fault evidence along the southeast margin of the valley it may be postulated that the greatest displacement was along this portion of the valley. In the area just west of Georgetown, Idaho, a recent railroad cut has exposed Salt Lake sediments dipping steeply to the east (figure 10). Therefore, if the "hinge" lies in this general region and the greatest displacement is on the eastern margin of the valley block the attitude of the Salt Lake sediments would be expected. However, as an alternate hypothesis the "hinge" or axis of movement may have been located south of the outlet, in the general region of Dingle, Idaho. This would provide an upward movement in the outlet area and a lowering of the southern portion of the valley block. Such a structural movement could have provided the dam.

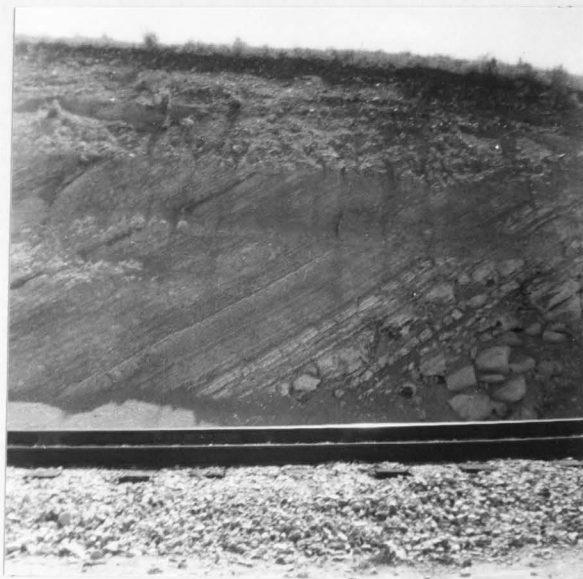


Fig. 10.--A view west of Georgetown, Idaho, showing the tilted Salt Lake group and the overlying veneer of alluvium

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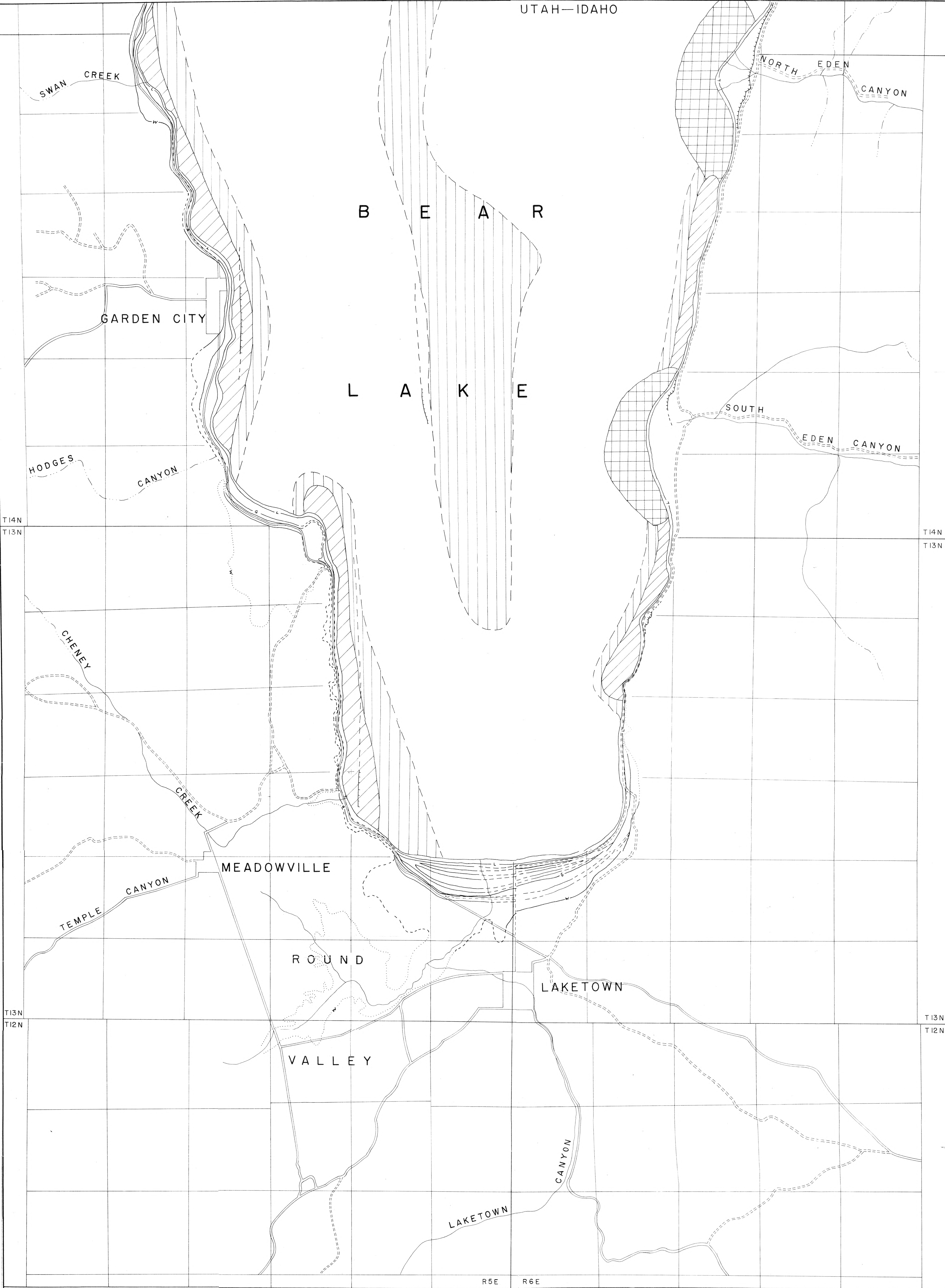
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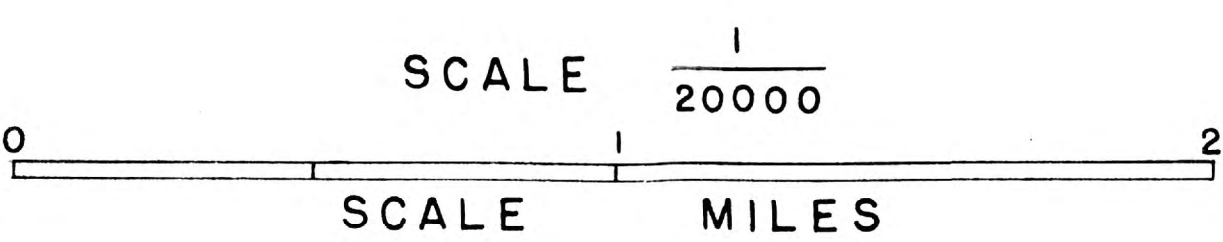
APPENDIX

Table 3. Climatological data (Lifton Station, Idaho)

Year	Temperature Annual Degrees F.	Precipitation Annual Inches	Evaporation April-October Inches	Wind Miles	Wind Direction
1922	40.7	9.42			N
1923	40.8	13.41			N
1924	40.9	7.1			N
1925					
1926	43.9	11.18			NW
1927	42.2	8.91			
1928	41.5	11.63			W
1929	40.8	8.30			NW
1930	41.0	10.40			NW
1931	41.8	6.16			NW
1932	40.1	7.88			NW
1933	42.0	6.98			SW
1934	46.7	6.21			NW
1935	41.4	6.78			NW
1936	42.3	12.77			NW
1937	40.6	11.87	5.946		NW
1938	42.7	10.18	6.512		SW
1939	43.2	7.15	7.006		SW
1940	45.2	9.26	7.258		SW
1941	42.6	12.69	6.136		SW
1942					
1943	42.7	10.24	6.924		SW
1944	40.3	9.47	6.660		SW
1945	40.3	14.59	5.683		SW
1946	41.0	13.10	6.292		SW
1947	42.4	12.85	5.777		
1948	40.6	8.31	6.352		
1949	40.1	10.49	7.74		
1950	41.9	12.57	6.09		NW
1951	41.1	11.57	6.09		N
1952	39.8	6.57	7.15	25.002	
1953	43.2	8.58	6.46	23.271	
1954	43.0	8.51	6.81	20.036	
1955	39.2	10.51	6.73	24.033	



SURFICIAL GEOLOGY OF BEAR LAKE VALLEY, UTAH



SHORELINES

	SHORE FEATURES PRESENT	POSITION BY ELEVATION	INFERRED POSITION
LIFTON	— L — L	- - - L - - -
GARDEN CITY	— G — G	- - - G - - -
WILLIS RANCH	— W — W	- - - W - - -

FAULT SCARPLETS

SCARPLET INFERRED

ROAD CLASSIFICATION

PAVED
SECONDARY

LAKE BOTTOM SEDIMENTS 30+ DEEP	□
LAKE BOTTOM SEDIMENTS 0-30 DEEP	▨
LAKE BOTTOM SEDIMENTS ABSENT	▩
DELTA DEPOSITS	▧

